

Flying IFR with GPS: How Much Practice Is Needed?

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ABSTRACT

Sixteen instrument-rated pilots with no prior experience with IFR GPS completed a program of ground study and five practice flights in an airplane. Eight pilots completed the ground study using a self-study program, while eight pilots received dual ground instruction. The ground study and flight practice covered knowledge and skills required by the instrument rating practical test standard that are affected by the use of IFR GPS. A detailed record was kept of errors made by pilots during each practice flight for six selected skills. The data were analyzed to determine: (1) whether or not the ground study and five practice flights were enough to allow pilots to master the skills; (2) how effective was self study compared to dual instruction; and (3) which skills presented pilots with the most difficulty and accounted for the most errors. The results show that pilots had still not reached proficiency after five practice flights, regardless of ground study method used. Furthermore, pilots were highly similar in the difficulties they encountered while acquiring these new skills. These results suggest that the learning challenges for proficient IFR GPS use are significant.

INTRODUCTION

Since the late 1990s, the installation of IFR-approved GPS units in general aviation aircraft has steadily increased. Initial studies of GPS usage [Heron et al, 1997; Henry et al, 1999; Adams et al, 2001] have prompted concern about what sorts of additional knowledge or experience might be required to safely use GPS as a primary means of navigation under instrument flight rules.

The FAA has slowly and conservatively taken advisory and regulatory steps toward insuring the safe use of IFR GPS. The Aeronautical Information Manual [FAA, 2004] has been expanded to include a section about IFR GPS. The Instrument Rating Practical

Test Standard has also been modified to require every pilot applicant to demonstrate proficiency with IFR GPS when an IFR GPS-equipped aircraft is used for a practical test.

The idea that additional training or experience might be required for IFR GPS is not only is a question of safety, but also a question of popular acceptance. Users of IFR GPS might object to new regulations that require additional and expensive pilot training if the need for such training was not carefully documented and made explicitly clear.

We studied a group of sixteen instrument-rated pilots with no prior experience with IFR GPS as they worked toward proficiency with flying under IFR with GPS. Pilots' learning efforts consisted of two parts: (1) ground study; and (2) five practice flights in which pilots practiced the skills they learned on the ground. Eight pilots completed the ground study through dual instruction, while eight pilots studied the same material on their own.

During the practice flights, a detailed record was made of all errors committed by pilots when practicing six selected skills. The skills are:

1. Program IFR flight plan and load GPS approach
2. Program and fly a VNAV descent
3. Demonstrate a straight-in GPS approach
4. Demonstrate a vectored GPS approach
5. Demonstrate a missed approach and hold
6. Demonstrate a GPS approach w/ procedure turn

The ground study and the flight practice covered other knowledge and skills required for safe and proficient use of IFR GPS, but they were not measured as part of the experiment.

Pilots' error data were analyzed to address three questions:

1. Was ground study and five practice flights enough for pilots to master the six skills?

2. How effective was self study compared to dual instruction?
3. Which skills presented pilots with the most difficulty and accounted for the most errors that pilots made?

METHOD

Participants

Sixteen instrument-rated pilots were recruited from local professional flight training schools. Pilots ranged from 120 to 3,700 hours of flight experience, with a median of 522 hours. Pilots were told they would not be paid for their participation but would receive instrument flight experience using IFR GPS. All pilots met the recent flight experience requirements set forth in 14 CFR 61.57 (c).

Procedure

Eight pilots were randomly assigned to the Self Study group and were told that they would be required to learn the new skills on their own. These pilots were assigned readings in a textbook [Casner, 2002] prior to each session. Pilots were told to master the material as best as they could, and that during the next session, they would have the opportunity to practice and demonstrate their newly learned skills in flight. It was emphasized that pilots' should attempt to master the skills such that they could demonstrate them without the need for intervention by the experimenter, although intervention would be available if needed. Rather than attempt to control the duration of self-study for experimental design purposes, our aim was to make this learning scenario as realistic as possible: as it might occur in everyday practice. Pilots were not asked to report the amount of time they had spent studying.

Eight pilots were randomly assigned to the Dual Instruction group and were told to do nothing to prepare for the flight sessions. These pilots were told that the experimenter would cover all of the concepts and skills needed for each flight during a dual ground instruction session immediately prior to the flight. The material presented during the dual instruction sessions was the same as that presented in the textbook read by pilots in the

Self Study condition. Pilots were told that they should attempt to master the skills such that they could demonstrate them without the need for intervention by the experimenter, although intervention would be available if needed. Dual instruction sessions continued until the pilots felt they were ready to successfully demonstrate the skills they had learned.

Both groups of pilots had access to a desktop IFR GPS unit that could be used to learn and practice GPS skills prior to each practice flight. The desktop IFR GPS unit was the same make and model installed in the airplane that was used for the practice flights.

For both groups, prior to each practice flight, the experimenter briefly reviewed the skills that would be needed during the flight, provided the pilot with charts covering the routes and approaches to be flown, and answered any questions the pilot had about the material.

The six skills were introduced before the practice flights as shown in Figure 1. Figure 1 also lists the number of times that each skill was practiced during each flight. It is important to note that not every skill was practiced on every flight. No new skills were introduced during the fifth practice flight.

	Flt 1	Flt 2	Flt 3	Flt 4	Flt 5
Skill					
Program IFR flight plan and load GPS approach	1	3	3	3	4
Program and fly a VNAV descent	1				1
Demonstrate a straight-in GPS approach	1			1	
Demonstrate a vectored GPS approach		3	3	1	3
Demonstrate a missed approach and hold			1		1
Demonstrate a GPS approach w/ procedure turn				1	1

Figure 1: Six IFR GPS skills practiced during the five practice flights.

Practice flights were conducted using the same protocol and evaluative technique used in similar studies of pilot proficiency [Talleur et al, 2003]. During the practice flights,

participants acted as sole manipulator of the controls under simulated instrument conditions (a standard view-limiting device was used). The experimenter rode in the right seat and acted as flight instructor and observer. A script for each flight was prepared in advance and used by the experimenter to ensure that each flight proceeded in accordance to a set plan, and that each pilot was asked to practice and perform the same skills in the same order. The scripts used for each flight are given in Appendix A.

A palmtop computer was used to record errors made by the pilot on any skill, or assistance requested by the pilot for any skill. A scorecard was kept for each pilot and flight. For each skill, if the pilot was able to demonstrate the skill without error or help from the experimenter, the pilot received a score of 1. If an error was made or help was provided, regardless of how subtle (e.g., words, gestures, sounds), a score of 0 was recorded for that skill. Help was provided by the experimenter only when the flight could no longer continue to the next step in the planned flight.

Results and Discussion

Figures 2(a) and 2(b) show the error rates for each of the skills during each of the five flights, across all pilots in the Self Study and the Dual Instruction groups. Error rate means the proportion of failed attempts to demonstrate each skill among the total number of attempts to demonstrate each skill, for all pilots in each condition. For example, in Figure 2(a), the error rate for the Program Route skill during the first flight is roughly 0.38. This means that pilots collectively succeeded in demonstrating the Program Route skill 62 percent of the time, and failed to demonstrate the skill 38 percent of the time, during the first flight. Recall that not every skill was demonstrated during every flight, hence, some skills appear fewer than five times in the graphs.

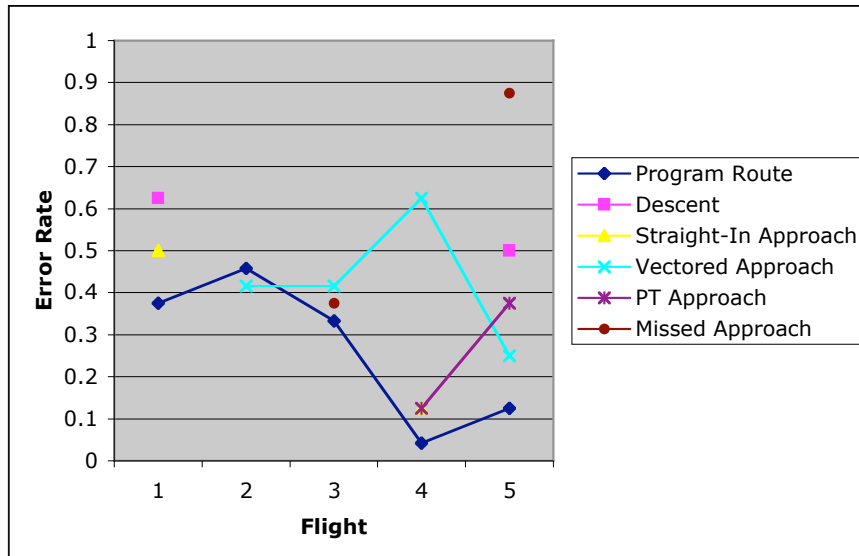


Figure 2(a): Error rates for the six skills (dual instruction)

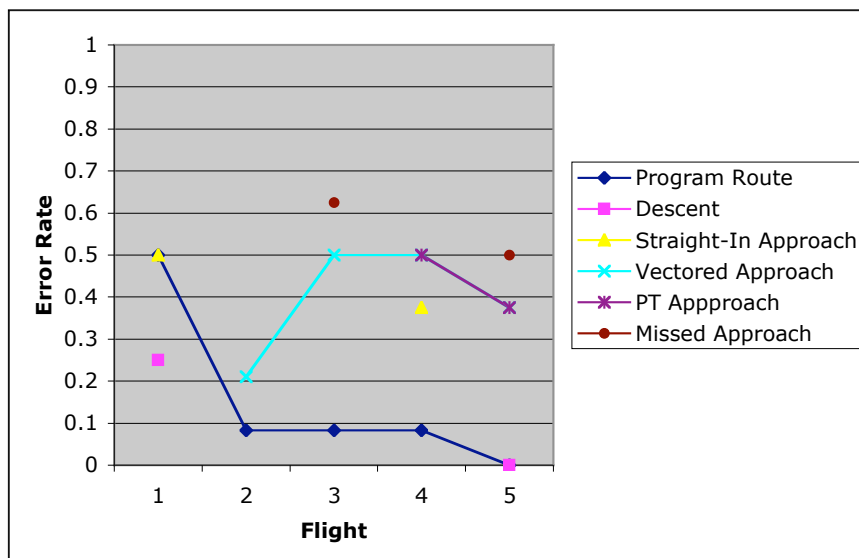


Figure 2(b): Error rates for the six skills (self study)

1. Were five practice flights enough?

The first question to address is whether or not ground study and five practice flights were enough to allow pilots to reach proficiency with the six skills. Looking at the data points for the later practice flights in both graphs in Figure 2 we can see that errors persist for most skills. Although pilots seemed to have mastered the knobs-and-dials procedures

needed to program a route, skills associated with flying instrument approaches seemed to require more practice.

The data in Figure 2(a-b) make it abundantly clear that our initial expectations of reaching proficiency after 2, 3, 4, or 5 practice trials were off the mark. Our expectations were based on the understanding that all pilots had already demonstrated proficiency for these same skills using different navigation systems (i.e., all pilots held an instrument rating and were instrument current). However, the data in Figure 2 does show that the likely number of needed practice trials for each skill is more than what was provided here.

To verify that the adage “practice makes perfect” is at work here, the number of practice trials for each skill was correlated with the error rates for the last trial in which each skill was practiced. For example, looking at Figure 2 (a), the Vectored Approach skill was practiced four times and the error rate was 0.25 on the final trial. Comparing these two numbers for each skill, the correlation coefficients for the Dual Instruction and Self-Study groups were -0.53 and -0.42 , respectively. That is, for both groups, high numbers of practice trials were associated with lower error rates. This result suggests that learning was occurring, only at a slower rate than what we had originally hypothesized.

2. Did having more total flight experience make a difference?

It is interesting to look at the relationship between the total flight experience of the participants in the study, and their error rates for the six skills. The correlation coefficient for total flight hours and error rates for the six skills for all sixteen pilots was $r=0.01$. This lack of correlation suggests that proficiency with IFR GPS is a separate set of skills to be acquired. Having extensive flight experience in airplanes not equipped with IFR GPS does not appear to help. Flying proficiently with IFR GPS seems to be the result of training and experience flying with IFR GPS.

3. Was there a difference between dual instruction and self study?

A third question to consider is whether or not there are any observed differences between the two methods of ground study: dual instruction and self study. Dual instruction seems to offer the advantage of two-way interaction between student and instructor. Self-study offers the advantage of a persistent record of the instructional material that can be later reviewed. It is interesting to note that none of the pilots in the Dual Instruction group made use of notes.

A simple comparison of mean error rates between the two groups for all six skills (i.e., the data shown in Figure 2) yielded no significant difference. Next, six t-tests were performed comparing the error rates for each of the six skills individually. Only the Build and Fly Descent task yielded a significant difference ($t = 2.65$, $p < 0.05$). Since this task was only practiced twice during the course of the five practice flights, no strong conclusions are warranted.

Overall, it seems that the two ground learning methods yielded similar results.

4. A more detailed breakdown of errors made on each of the six skills

Figures 3 through 8 show the specific criteria that were used to determine success or failure for each of the six tested skills. The data in Figures 3 through 8 break down overall performance for each skill into performance on component sub-skills. Figures 3 through 8 list the sub-skills associated with each skill, and show the proportion of cases for which each sub-skill was a contributing factor in pilots' failure to perform each of the six skills.

Since no significant differences were found between the two learning methods, Figures 3 through 8 combine the results for the two ground learning methods.

Program Route and Install GPS Approach

The Route Programming skill consisted of two sub-skills shown in Figure 3.

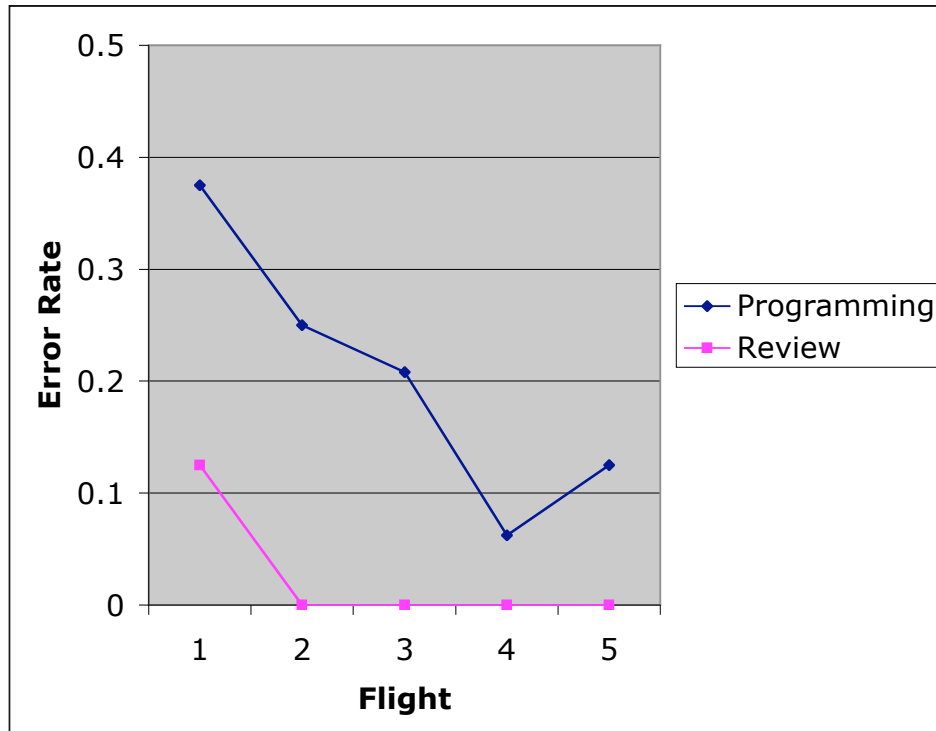


Figure 3: Sub-skills that comprise the Program Route skill.

The Programming sub-skill required pilots to recall and perform the knobs-and-dials procedures needed to install the route. This sub-skill is essentially a memory task aided by any cues provided by the GPS unit interface. For example, a button marked FPLN might allow pilots to successfully reach the flight planning page when the procedure has not been memorized. The Programming sub-skill was the principle cause for the occasional unsatisfactory performance for the Route Programming task.

The Review sub-skill requires pilots to remember to review the accuracy of a flight route once it is installed. Pilots seemed to have well grasped the importance of checking their work.

Build and Fly a Descent

The Descent skill consisted of two sub-skills shown in Figure 4. Recall that the Build and Fly a Descent skill was only demonstrated during the first and fifth flights.

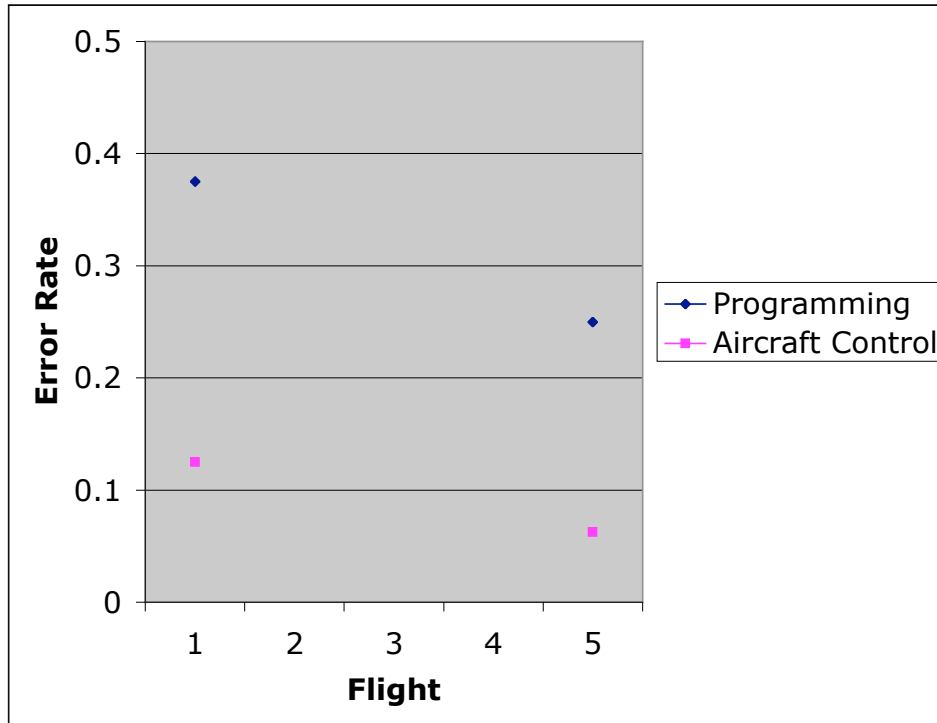


Figure 4: Sub-skills that comprise the Descent skill.

The Programming sub-skill requires pilots to recall the knobs-and-dials procedure required to build a VNAV descent path. Again, the Programming sub-skill was the primary cause of errors. Since the Descent skill was only practiced twice in flight, the high error rate observed for this skill cannot be regarded with any certainty. In fact, the two data points in Figure 4 exactly match the improvement trajectory observed for the programming sub-skill for the Program Route skill (see Figure 4).

The Aircraft Control sub-skill required pilots to meet the crossing restriction they had programmed. Errors on this sub-skill were related to inattention: failure to start the descent at the top-of-descent point computed by the GPS unit, or failure to maintain the target rate of descent.

Straight-In GPS Approach

The most basic type of GPS approach was scored with three sub-skills shown in Figure 5. This skill was demonstrated only during the first and fourth flights.

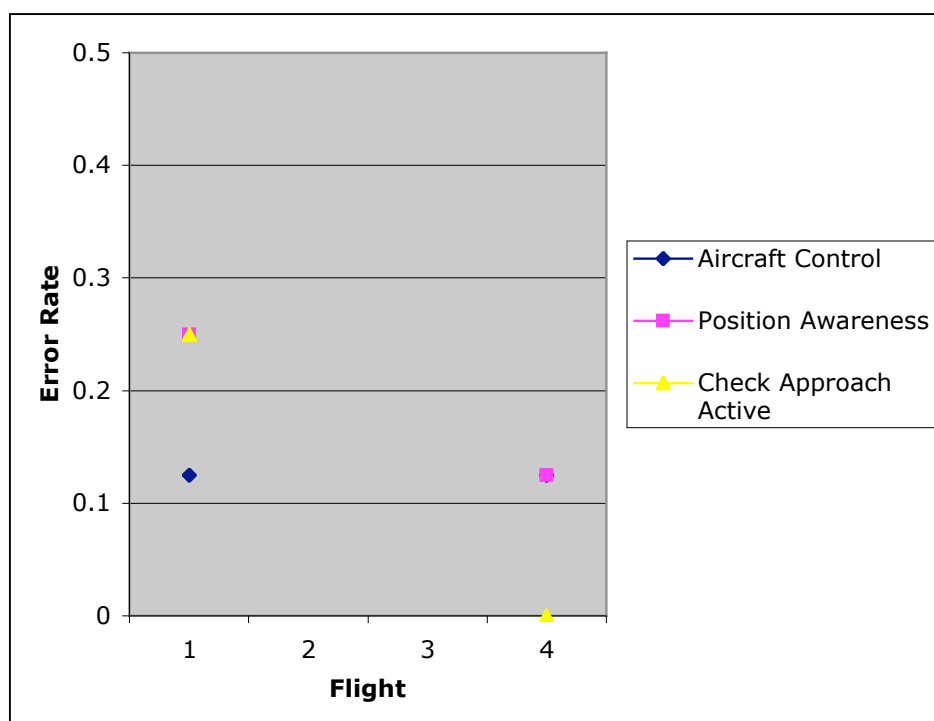


Figure 5: Sub-skills that comprise the Straight-In Approach skill.

The Check Approach Active sub-skill is particularly important. Every IFR-approved GPS unit features an annunciation that informs the pilot that all necessary conditions are met to continue an approach beyond the final approach fix and descend to the minimum descent altitude (MDA). Continuing the approach without an approach active indication could result in disastrous consequences since the integrity of the course guidance is not guaranteed. Pilots initially struggled with this important skill but seem to have resolved the problem by the end of the practice flights.

The Aircraft Control sub-skill was a simple measure of how frequently pilots deviated more than 100 feet from a required altitude, or allowed a full-scale deflection of the CDI needle. It is widely known by instructors and pilots alike that aircraft control performance varies when workload is increased and distractions are introduced.

The Position Awareness sub-skill resulted in an error when pilots failed to announce their position at an important approach waypoint, or took a required action at an inappropriate place. Several pilots began a descent to the MDA prior to reaching the final approach fix.

Vectored GPS Approach

Five sub-skills shown in Figure 6 comprised this more sophisticated type of GPS approach. This skill was not demonstrated by pilots during the first flight.

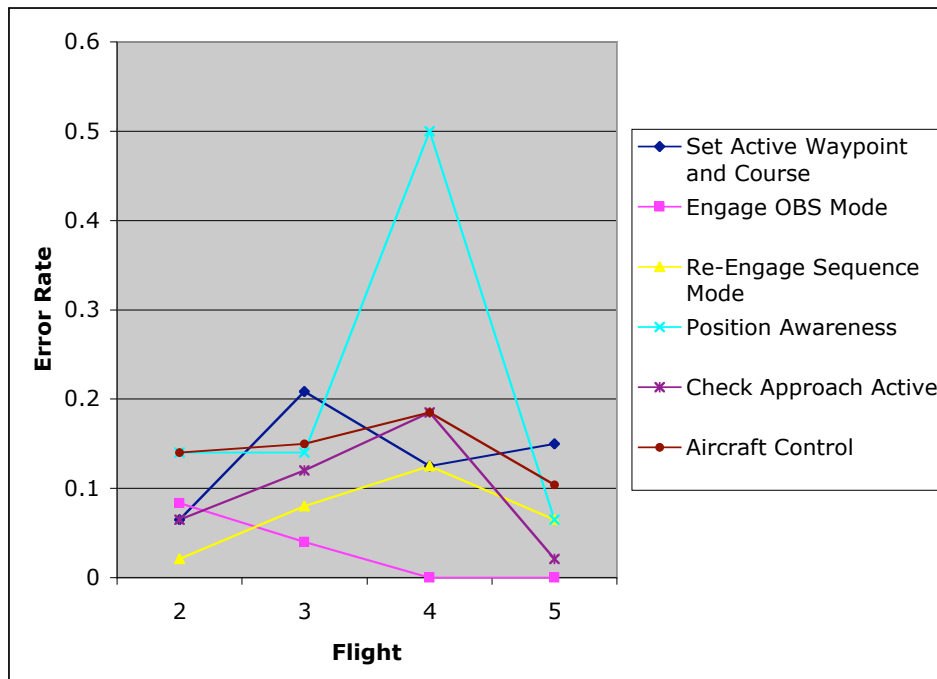


Figure 6: Sub-skills that comprise the Vectored Approach skill.

The Set Active Waypoint and Course sub-skill required pilots to change the active waypoint in the GPS computer to a different waypoint that was farther ahead in the approach procedure. This is required when ATC vectors the pilot inside of the initial approach fix in order to shorten an approach. Error rates for this sub-skill never significantly improved over the course of five flights. The consequences of making an error on this sub-skill are severe. Entering the wrong waypoint or course means that the pilot is following a course other than the published approach course.

The Engage OBS Mode sub-skill requires pilots to engage the GPS unit's non-sequencing mode, which allows the pilot to use the OBS knob to dial arbitrary courses to any waypoint. For this type of approach, the pilot dials in the final approach course. Pilots seem to have mastered this sub-skill quickly.

The Re-Engage Sequence Mode sub-skill is somewhat challenging in that it requires pilots to remember to take a future action, a cockpit memory task known to be difficult [Nowinski et al, 2003]. Pilots were still forgetting roughly seven percent of the time even after five practice flights.

Errors on the Position Awareness, Check Approach Active, and Aircraft Control sub-skills continued to be somewhat problematic for vectored approaches.

Missed Approach and Hold

The Missed Approach and Hold skill was scored using the five sub-skills shown in Figure 7. This skill was only demonstrated during the third and fifth flights.

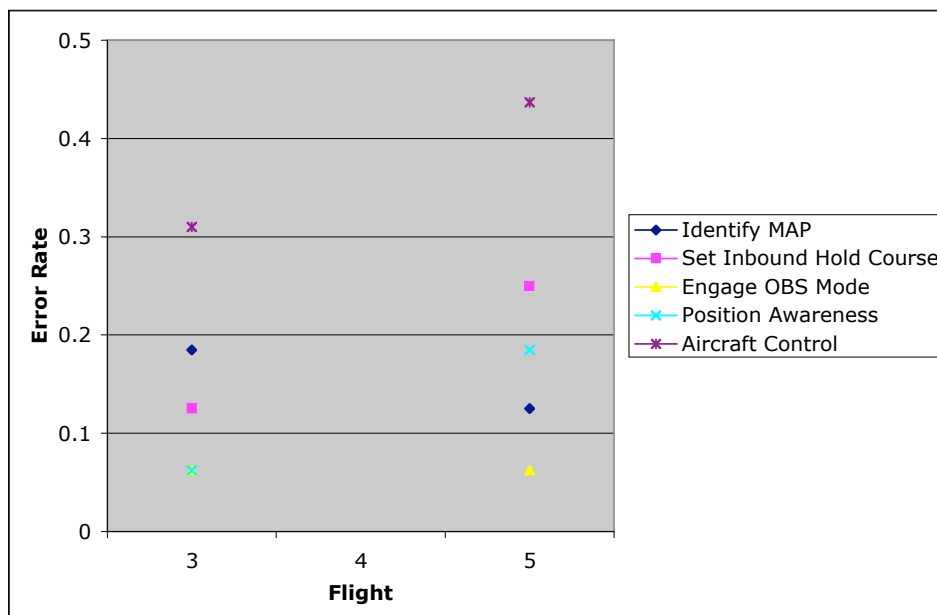


Figure 7: Sub-skills that comprise the Missed Approach and Hold skill.

Identify Missed Approach Point is another sub-skill with potentially serious consequences. Pilots failed to recognize the missed approach point roughly 12% of the time on their second missed approach procedure. One pilot overran the missed approach point by 2.4 NM. This sub-skill is particularly worrisome because the sixteen pilots have already demonstrated their ability to recognize missed approach points using other navigation systems.

The two practice trials proved insufficient for most other sub-skills. Pilots consistently had trouble dialing the correct inbound hold course and in controlling the aircraft.

GPS Approach with Procedure Turn

The GPS Approach with Procedure Turn sub-skill was scored using the five sub-skills shown in Figure 8. This skill was demonstrated during the fourth and fifth flights.

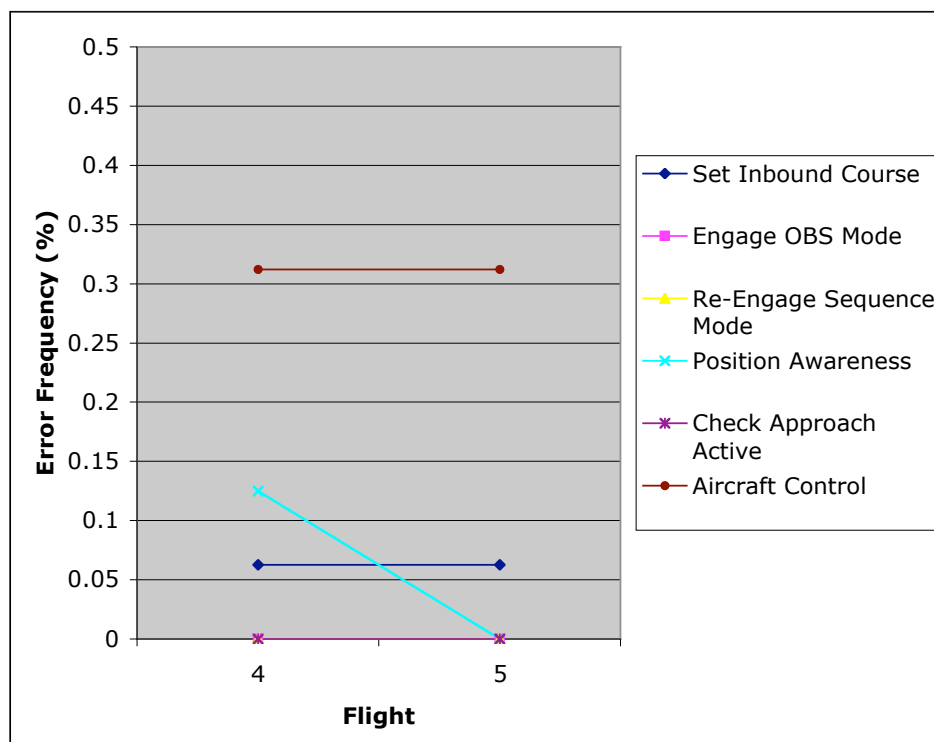


Figure 8: Sub-skills that comprise the Procedure Turn Approach skill.

After two practice trials, pilots were still sometimes failing to dial the inbound hold course, and were still experiencing problems with aircraft control.

5. Did similar skills result in similar performance?

Looking at the sub-skills listed in Figures 3 through 8, we notice that some skills require the pilot to perform similar sub-skills. For example, Position Awareness and Aircraft Control are both required sub-skills for all four approach-related skills. Similarly, Engage OBS Mode, Re-Engage Sequence Mode, and Check Approach Active are common to the Vectored and Procedure Turn Approach skills. It is interesting to note whether or not performance on sub-skills were similar across different skills that used them. It may be that sub-skills that are learned and practiced on one skill might help expedite learning and improve performance on later skills that use them.

Development of sub-skills related to engaging or monitoring modes appeared to follow a similar trajectory across skills. The Check Approach Active sub-skill seems to have been soundly learned by Flight 5 for all three GPS approach skills (Straight-in, Vectored, and Procedure Turn). It is not clear whether or not practicing this sub-skill in three different contexts helped to develop a more general skill. The Re-Engage Sequence Mode sub-skill is another memory-related skill that presented most pilots with initial difficulty. This sub-skill was also well mastered across the Vectored and Procedure Turn Approach skills.

There appears to be little similarity among performance on the Aircraft Control sub-skill across the different skills. Pilots who flew within tolerances for some skills were sometimes quite out of control during performance of other skills. This casts doubt on theories that claim that aircraft control is an indicator of a more general division of attention skill that, once mastered, applies to pilot performance in the large.

CONCLUSION

After ground study and five practice flights in an airplane, the data show that the pilots we studied had not yet reached proficiency for our six instrument flying skills when GPS

was used at the primary navigation system. It important to recall that these six skills were drawn from the Instrument Rating – Airplane practical test standards [FAA, 1998] and are ones for which each pilot had already been formally tested and certified to perform while acting as pilot-in-command in instrument flight conditions. At the present time, no additional training or qualifications are required for pilots to exercise the privileges of an instrument rating using GPS as the primary means of navigation.

How much practice is needed then? In short, we have failed to answer our original question in much detail. The only answer that can be provided by the data and analysis given here is that it is likely that more than five ground learning sessions and five flights are required for the average pilot. It is clear that another study must be done in which pilots are permitted to continue practicing until reaching a point of asymptotic performance. It must be noted for the present study that not all skills were practiced on every flight. Indeed, at the end of the training, pilots performed most poorly on skills that they had practiced only a few times. Future studies might be designed to carefully control the number of practice trials for each skill, not just the number of flights.

These results suggest that IFR GPS is not a “walk-up-and-use” system for pilots at any experience level. Considerable learning and practice are required to achieve proficiency with flying IFR with GPS.

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Appendix 1

Script of Events Used for the IFR GPS Practice Flights

Flight 1: SQL-O27-SQL

SQL-O27

Program SQL-Sunol-Tracy-ECA-O27 on ground
Announce Sunol
Program VNAV ECA @ 3,000
Announce Tracy
Announce ECA
Announce Moter
Announce approach active mode
Announce Eltro
Aircraft control

O27-SQL

Program O27 to SQL on ground
Insert Tracy and Sunol
Program diversion
Look up rwy length and frequency
Program Sunol to SQL
Aircraft control

Flight 2: SQL-MOD-SCK-LVK-SQL

SQL-MOD

Program SQL-Sunol-Tracy-Cazli-MOD on ground
Set OBS 009 to Sunol
Set GPS to sequencing mode
Announce Sunol
Announce Tracy
Set OBS 018 to Awoni
Announce Awoni
Set GPS to sequencing mode
Announce approach active mode
Announce Wowar
Aircraft control

MOD-SCK

Program MOD-SCK on ground
Set OBS 291 to Oxjef
Set GPS to sequencing mode once established
Announce Oxjef
Announce approach active mode
Announce Ipdew
Aircraft control

SCK-LVK

Program SCK-LVK on ground

Set OBS 246 to Uhhut
Set GPS to sequencing mode
Announce Uhhut
Announce approach active mode
Announce Oyahi
Aircraft control

Flight 3: SQL-STS-KDVO-O69-SQL

SQL-STS

Program SQL-STS
Set OBS 321 to Zijbe
Set GPS to sequencing mode
Announce Zijbe
Announce approach active mode
Announce Gokuw
Aircraft control

STS-DVO

Program STS-DVO on ground
Set OBS course to Oriby
Announce Oriby
Announce approach active mode
Announce Eyeji
Program direct to SGD
Set OBS 180 to SGD for hold
Program SGD-O69
Aircraft control

DVO-O69

Set OBS 268 to Ipary
Set GPS to sequencing mode when established
Announce approach active mode
Announce Ipary
Aircraft control

Flight 4: SQL-MRY-WVI-HAF-SQL

SQL-MRY

Program SQL-OSI-Sapid-Santy-Mover-SNS-Llynn-MRY on ground
Engage Heading Select
Engage VS and arm Altitude Hold
Set OBS 141 to Sapid
Arm Nav to capture course
Set GPS to sequencing mode
Announce Sapid
Engage VS and arm Altitude Hold
Announce Santy
Engage Heading Select
Set OBS 286 to Raine

Arm Approach to capture course
Set GPS to sequencing mode when established
Announce approach active mode
Announce Raine
Announce 7.2NM waypoint

MRY-WVI

Program MRY-WVI on ground
Engage VS and arm Altitude Hold
Set OBS 314 to Dyner
Arm Approach to capture course
Set GPS to sequencing mode when established
Announce approach active mode
Announce Dyner

WVI-HAF

Program WVI-HAF on ground
Announce Giruc
Set GPS to OBS mode for hold
Set GPS to sequencing mode
Engage Approach to capture course
Announce approach active mode
Announce Wohli

Flight 5: SQL-O27-SCK-103-LVK-SQL

SQL-O27

Program SQL-Sunol-Tracy-ECA-O27 on ground
Announce Sunol
Engage VS and arm Altitude Hold
Program VNAV ECA @ 3,000
Engage VS and arm Altitude Hold
Announce Tracy
Set OBS 090 to Moter
Engage Heading Select and arm Approach
Set GPS to sequencing mode
Announce Moter
Announce approach active mode
Announce Eltro
Program direct Wraps
Use autopilot to accomplish missed approach
Set OBS 180 Wraps for hold
Announce Wraps

Wraps-SCK

Program Wraps-SCK
Set OBS 234 to Oxjef
Engage VS and arm Altitude Hold
Engage Heading Select and arm Approach
Set GPS to sequencing mode when established

Announce approach active mode

Announce Ip dew

SCK-103

Program SCK-103

Set OBS 285 to Quads for PT

Use autopilot to accomplish PT

Announce Quads

Set GPS to sequencing mode inbound to Quads

Engage approach function

Announce approach active mode

Announce Quads

103-LVK

Program 103-LVK

Engage VS and arm Altitude Hold

Set OBS 246 to Uhhut

Engage Heading Select and arm Approach

Set GPS to sequencing mode when established

Announce Uhhut

Announce approach active mode

Announce Oyahi